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01 Transport in Plants

1. Introduction :

In a **flowering plant** substance that would need to be transported are **water, mineral nutrients, organic nutrients and plant growth regulators / hormones.** The **small distance transport** means transport with in the cell or across the membrane or from cell to cell in a tissue occurs by **diffusion, facilitated diffusion (passive transport) and by Active transport.** Transport over **longer distance** proceeds through the vascular system (the xylem and the phloem) and is called **translocation**.

Direction of Transport :

(i) In rooted plants transport in xylem (of water and minerals) is unidirectional, from roots to stem.

(ii) **Organic and mineral nutrients however, undergo multidirectional transport.** Organic compounds synthesised in the photosynthetic leaves are exported to all other parts of the plant including storage organs. From the storage organs they are later re-exported. The mineral nutrients are taken up by the roots and transported upwards into the stem, leaves and the growing regions. When any plant part undergoes senescence, nutrients may be withdrawn from such regions and moved to the growing parts.

(iii) Hormones or plant growth regulators and other chemical stimuli are also transported, though in very small amounts, sometimes in a strictly polarised or unidirectional manner from where they are synthesised to other parts. Hence, in a flowering plant there is a complex traffic of compounds (but probably very orderly) moving in different directions, each organ receiving some substances and giving out some others.

2. Means or types of transport : Transport in plants is of two types –

(A) Short distance transport (B) Long distance transport

(A) Short distance transport :

- If transport occurs within the cell or from one cell to another cell then it is considered as short distance transport. Further it is of two types –

  (i) Passive transport (ii) Active transport

(i) Passive transport :

- If transport occurs according to concentration gradient (High concentration to low concentration) without expenditure of ATP. It occurs by following methods –

  (a) Simple diffusion (b) Facilitated diffusion

(a) Simple Diffusion :

- **"The movement of molecules or atoms or ions of a material from an area of higher concentration to an area of their lower concentration is called diffusion."**

  e.g. Diffusion of odour of perfume, spreading of crystals of $KMnO_4$ in water.

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- **The diffusion is continued till the dynamic equilibrium is not established.** At this stage the movement of molecules is equal in both the direction, so net movement is zero.
- **Diffusion is a slow process** it can account for only short distance of molecule for e.g. for movement of a molecule across a typical plant cell (about 50 mm) takes approximately 2.5 second.
- Diffusion is not dependent on a living system.
- Diffusion is obvious in gases and liquids but diffusion in solids is more likely rather than of solids.

Diffusion rate → Gas > Liquid > Solid

- Diffusion of each substance is free from diffusion of other substance. Like diffusion of CO_2 and O_2 occurs at the same time in different directions through stomata.
- Diffusion can occur in both manners - without any membrane or through the membrane.
- **Factors affecting diffusion rate - Concentration gradient, permeability of membrane, temperature and pressure.**
- The diffused molecules or ions exert a pressure on the substance or medium in which diffusion takes place, known as diffusion pressure.

Significance of Diffusion :

(1) **Exchange of gases** like CO_2, O_2 between plant and atmosphere, occur through diffusion.
(2) It is the only means for gaseous movement within the plant body.
(3) The process of **transpiration** is also a diffusion. The evaporation of water from the intercellular spaces is linked with diffusion during the transpiration.

(b) Facilitated Diffusion :

- Diffusion of any substance depends upon solubility in main constituent of membrane, lipid. **Lipid soluble substance rapidly diffuse through the membrane.**
- **Moiety of which substance is hydrophilic, diffuses difficultly through membrane. So need to simplify its movement. Membrane proteins provide space for transfer of these molecules. This process is called facilitated diffusion.**
- In facilitated diffusion, specific proteins help in transfer of substances across the membrane and no ATP is consumed. These specific proteins do not setup a concentration gradient, a concentration gradient must already be present for molecules to diffuse even if facilitated by the proteins.
- **Transport rate reaches maximum when all of the protein transporters are being used (saturation).**
- **Facilitated diffusion is very specific, it allows cell to select substances for uptake.**
- **It is sensitive to inhibitors which react with protein side chains.**
- The proteins form channels in the membrane for molecules to pass through. Some channels are always open, others can be controlled. Some are large, allowing a variety of molecules to cross.
- **The porins are proteins that form huge pores in the outer membranes of the plastids, mitochondria and some bacteria allowing molecules up to the size of small proteins to pass through.**

e.g. Water channels are made up of 8 different types of aquaporins.
(i) In **symport,** two molecules move across the membrane in similar direction.
(ii) **Antiport** they move in opposite directions.
(iii) A molecule moves freely across the membrane then this method is called **uniport.**

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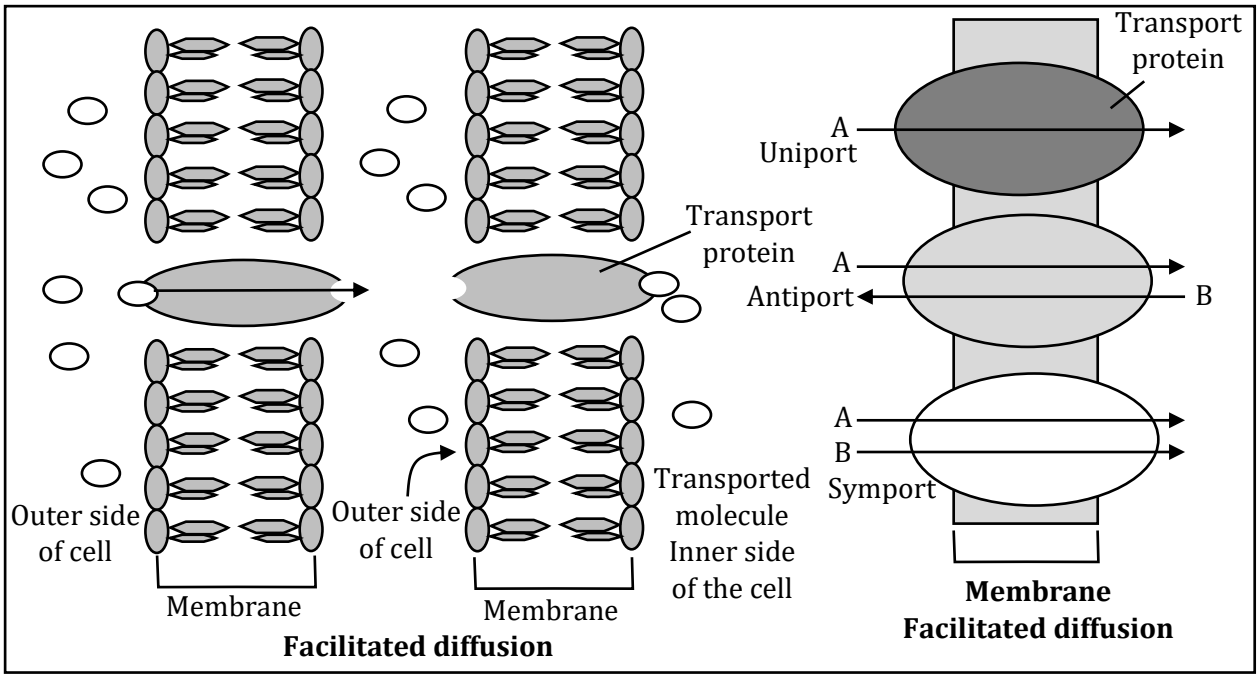

(ii) Active Transport :

- **Active transport uses energy to transport and pump molecules against a concentration gradient.** Active transport is carried out by membrane proteins. Hence different proteins in the membrane play a major role in both active as well as passive transport.
- **Pumps are proteins that use energy to carry substances across the cell membrane**. These pumps can transport substances from a low concentration to a high concentration ('uphill' transport).
- Transport rate reaches a maximum when all the protein transporters are being used or are saturated. Like enzymes the carrier protein is very specific in what it carries across the membrane. These proteins are sensitive to inhibitors that react with protein side chains.

Comparison different transport processes

Property	Simple diffusion	Facilitated transport	Active transport
Requires special membrane proteins	No	Yes	Yes
Highly selective	No	Yes	Yes
Transport saturates	No	Yes	Yes
Sensitivity to inhibitors	No	Yes	Yes
Hormonal regulation	No	Yes	Yes
Uphill transport	No	No	Yes
Requires ATP energy	No	No	Yes

3. Permeability :

- The extent to which a membrane permits or restricts the movement of a substance is called membrane permeability.
- The membrane are of four types on the basis of permeability: -

(i) Permeable membrane : Such membrane is permeable for both - solutes and solvent. e.g. cellulosic cell wall of living cells, filter paper.

(ii) Semipermeable Membrane : Such membrane allows diffusion of solvent molecules rapidly but does not allow solutes. e.g. Artificial membranes like Cellophane and Copper ferrocyanide membranes, parchment paper.

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(iii) **Selectively permeable Membrane or differentially permeable membrane: -** Such membrane allows some selective solutes to pass through them along with the solvent molecules. e.g. Cell membrane, tonoplast, membrane of cell organelles.

(iv) **Impermeable membrane: -** Membranes which do not allow both solvents to pass through it. e.g. cell wall of non-living cell like suberised cell wall.

4. Types of Solutions :

(i) **Isotonic solution :** If solution in which a cell is placed, has equal concentration to that of cytoplasm and cell sap then solution is called isotonic solution.

(ii) **Hypotonic solution :** If the concentration of outer solution is less than that of the cytoplasm and cell sap then solution is called hypotonic solution.

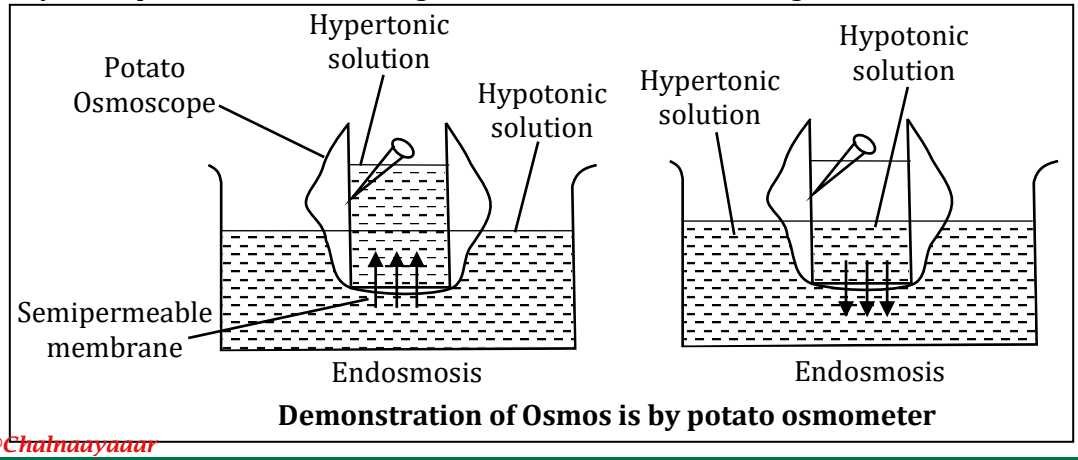
(iii) **Hypertonic solution :** If the concentration of outer solution is higher than that of the cytoplasm and cell sap such solution is known as hypertonic solution.

5. Plant Water Relations :

- Water is essential for all physiological activities of the plant and plays a very important role in all living organisms. It provides the medium in which most substances are dissolved.
- The protoplasm of the cells is nothing but water in which different molecules are dissolved and (several particles) suspended.
- A watermelon has over 92 percent water, most herbaceous plants have only about 10 to 15 percent of its fresh weight as dry matter.
- Distribution of water within a plant varies - woody parts have relatively very little water, while soft parts mostly contain water.
- A mature corn plant absorbs almost three litres of water in a day, while a mustard plant absorbs water equal to its own weight in about 5 hours.
- Because of this high demand for water, it is not surprising that water is often the limiting factor for plant growth and productivity in both agricultural and natural environments.

(A) Osmosis and Osmotic Pressure :

- **"Osmosis is defined as the diffusion of solvent (like water) from the solution of lower concentration (Hypotonic) to the solution of higher concentration (Hypertonic) when both are separated by a semipermeable membrane."**
- The net direction and rate of osmosis depends on both the pressure gradient and concentration gradient.
- **Demonstration of osmosis by potato osmometer :** If the potato tuber is placed in water, the cavity in the potato tuber containing a concentrated solution of sugar collects water due to osmosis.



Demonstration of Osmos is by potato osmometer

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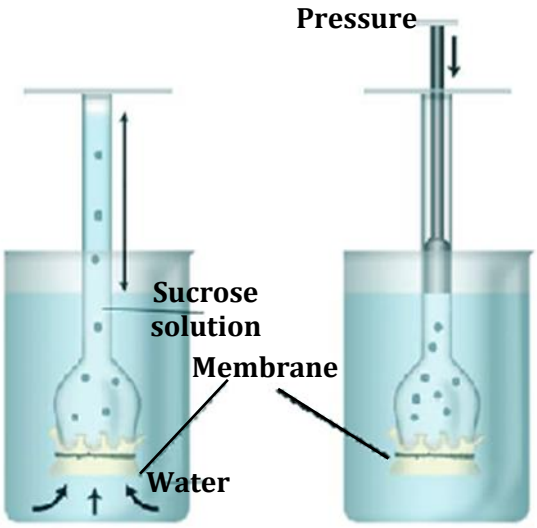
- **O.P. of a solution is equal to the pressure, required to prevent the water from diffusing in Hypertonic solution.**



Demonstration of osmosis. A thistle funnel is filled with sucrose solution and kept inverted in a beaker containing water.
(a) Water will diffuse across the membrane (as shown by arrows) to raise the level of the solution in the funnel
(b) Pressure can be applied as shown to stop the water movement into the funnel.

- **The osmotic pressure of pure water is zero.** O.P. is due to the presence of solute in the solution.

$$\boxed{OP \propto \text{Concentration of solute}}$$

- According to Hariss, the osmotic pressure is highest in leaves and lowest in roots.
- Generally osmotic pressure is less during the night and higher at noon.
- **Sequence of OP : Hydrophytes < Mesophytes < Xerophytes < Halophytes.**
- The highest osmotic pressure is found in the halophytes. **Highest OP is found in a Halophyte plant *Atriplex confertifolia* (202 atm.)**
- Osmotic pressure of a solution is measured by Osmometer.

➢ The osmotic pressure can be calculated by various methods :-

- The formula of Van't Hoff for measuring O.P. :

$$\boxed{OP = mRT}$$

Here m = molar concentration
R = Gas constant [0.082 mole/molecules]
T = Absolute temperature

the osmotic pressure of 1 M glucose solution at 0°C -

$OP \Rightarrow 1 \times 0.082 \times 273$
$\Rightarrow$ 22.4 atm.

- This formula is only for Non-ionising substances or non-electrolytes.

➢ The O.P. of electrolytes can be calculated by the following formula -

$$\boxed{OP = imRT}$$

- Where "i" is the ionisation constant of electrolytes.

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- The osmotic pressure of electrolytes is higher than that of non-electrolytes.
- For example - solution of 1 M NaCl and 1 M glucose. The molar concentration of both solutions are equal but O.P. of 1 M NaCl is higher than solution of 1 M glucose.
- Water moves from lower O.P. to higher O.P.
- When the water moves into the cell during the osmosis, it is called Endosmosis.
  e.g. Swelling of Raisins placed in water.
- When the water moves out of the cell then it is called Exosmosis.
  e.g. Shrinking of swollen raisins in highly concentrated sugar solution.

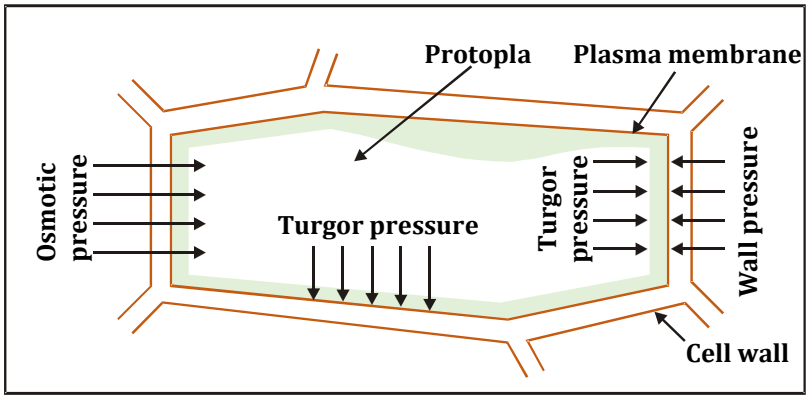
(B) Turgor Pressure (T.P.) and Wall Pressure (W.P.) :

- **When a cell is immersed in water, then water enters into the cell, due to which cytoplasm or protoplast apply a pressure to the cell wall which is called turgor pressure."**
- The turgor pressure is balanced by an equal but opposite pressure of the thick cell wall known as wall pressure. wall pressure and turgor pressure are equal but the direction is opposite.

T.P. = W.P.

- **Turgor pressure is not applicable for free solution. It is only applicable for osmotic system.**

- Plant cell does not burst when placed in a pure water due to wall pressure but an animal cell bursts when placed in pure water because wall pressure is absent due to absence of cell wall. When placed in distil water, RBCs are found to have burst.
- Turgor pressure is ultimately responsible for enlargement and extension growth of cell.



(C) Plasmolysis :

- **If a plant cell is placed in a hypertonic solution, water diffuses out of the cell. As a result, the protoplast of the cell is detached from the cell wall and starts shrinking. This is called plasmolysis.**
- **Water first lost from cytoplasm then from vacuole.**
- In plasmolysed cell external solution (hypertonic solution) is found in space between cell wall and protoplast.

Significance of Plasmolysis:

[1] If the plasmolysis continues for long duration in a cell then it dies. To destroy weeds, salt is used around their roots.

[2] Fishes and meats are prevented from spoilage by salting, which inhibits the growth of bacteria and fungus.

[3] Higher concentration of sugar in jams and jellies stops the growth of bacteria and fungi.

[4] High amount of chemical fertilizers near the root causes death or browning of the plant due to plasmolysis.

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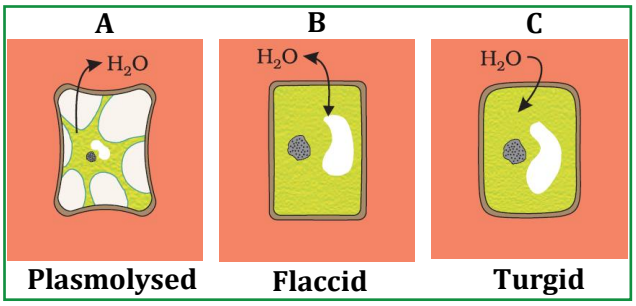
- The process of plamolysis is usually reversible. When the cells are placed in a hypotonic solution water diffuses into the cell causing the cytoplasm or protoplast to build up a pressure against the wall.
- A flaccid cell has zero turgor pressure.
- The highest value of turgor pressure is found in fully turgid cell and it is equal to the osmotic pressure. **OP = TP**
- The value of turgor pressure is normally from zero to the value of osmotic pressure in plant cell.
- The value of turgor pressure is assumed as negative (–ve) during the plasmolysis of the cell. (Here negative means decreasing turgor pressure)



(D) Diffusion Pressure Deficit (DPD) Or Suction Pressure (SP) :

- The decrease in the diffusion pressure of water in any system by addition of solutes is called DPD.
- DPD determines the direction of osmosis and it is the power of absorption of water for the cell. (Suction pressure). This is also known as demand of water in cell.

OP ∝ Concentration of solute

- **The diffusion of water or solvent takes place from the region of lower DPD to the region of higher DPD during the process of osmosis.**
- The DPD can be applied for different stages of cell as under –

(I) Partially Turgid cell or normal cell :– **DPD = OP – TP**

(II) Fully turgid cell :-

- When a cell is placed in pure water or hypotonic solution than cell sap, then water enters into the cell, so turgor pressure is developed in the cell. The cell starts swelling due to the turgor pressure. Simultaneously, concentration of cell sap decreases due to continuous inflow of water. Therefore, OP decreases but T.P. increases. When value of TP is equal to the OP the DPD becomes zero. At this stage cell becomes fully turgid. Therefore in a fully turgid cell -

  DPD = OP - TP

  When, OP = TP then OP – TP = O

  So, **DPD = 0**

(III) Flaccid cell :-

- If, the cell is in flaccid state then its T.P or WP would be zero and value of DPD would be equal to OP.

  TP or WP = O

  Therefore **DPD or SP = PP**

(IV) Plasmolysed cell :–

- Sometimes the value of turgor pressure is negative as in plasmolysed cell.

  In this state **DPD = OP – TP**

  TP = – ve

  DPD = OP – (– TP) = OP + TP

  DPD = OP + TP

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- **Demand of water in cells :-**

  Plasmolysed cell > Flaccid cell > Partially turgid cell or Normal cell > Fully turgid cell.

  Ex.

A - Cell		B - Cell
OP = 30 atm		OP = 25
TP = 25 atm		TP = 10
DPD = 5 atm		DPD = 15
Lower DPD	$\xrightarrow{H_2O}$	Higher DPD

(E) Water Potential (ψ_w) :

- **The kinetic energy or free energy of water molecules in any system is called system's water potential/chemical potential.**
- Now a days according to concept of free energy and thermodynamics DPD of solution is also represented by Water potential.
- **The water potential of pure water is maximum because pure water has maximum kinetic energy or free energy. The value of water potential of pure water is taken to be zero. (When system or pure water is only under atmospheric pressure and any other external pressure is not applied).**
- **Water always flows from higher water potential to lower water potential.**
- Water potential is represented by Greek word ψ(Psi)/ψ_W and it is measured in bars or Pascal (Pa).

  Water potential is equal to DPD but opposite in sign. Its value is negative.

$$\boxed{\Psi_w = -DPD}$$

- Water potential is determined by following components :

(F) Osmotic potential /Solute potential (ψ_S) :

- The decrease in water potential due to addition of solutes in a system is called solute potential. It is shown by negative sign (–ve).
- The more the solute molecules the lower (more negative) is the ψ_S.

$$\boxed{\Psi_s = -OP}$$

(G) Pressure Potential (Ψ_P) :

- The increase in water potential due to external pressure is called pressure potential. It is shown by positive sign (+ve).

$$\boxed{\Psi_p = TP} \qquad \boxed{\Psi_w = \Psi_s + \Psi_p}$$

At atmospheric pressure –

$$\boxed{\Psi_w = \Psi_s}$$

(a) Solution of which chamber has a lower water potential?

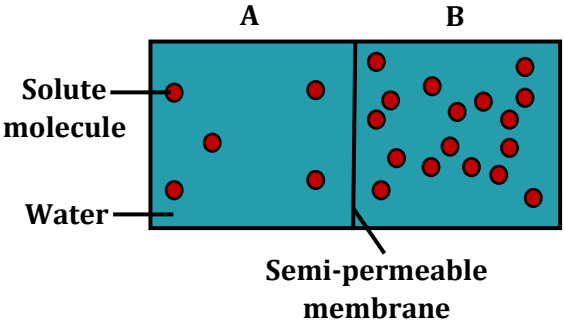
Ans. **B**

(b) Solution of which chamber has a lower solute potential?

Ans. **B**

(c) In which direction will osmosis occur?

Ans. **A to B**



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(d) Which solution has a higher solute potential?

Ans. **A**

(e) At equilibrium which chamber will have lower water potential?

Ans. **None**

(f) If one chamber has a ψ of –2000 kPa, and the other –1000 kPa, which is the chamber that has the higher ψ?

Ans. **Chamber of –1000 kPa.**

(g) What will be the direction of the movement of water when two solutions with ψ_w=0.2 MPa and ψ_w=0.1 MPa are separated by a selectively permeable membrane?

Ans. **0.2MPa to 0.1 MPa.**

Imbibition :

- **Adsorption of liquid by any solid material is called imbibition. It is also a type of diffusion.**
- Water or any other liquid which is adsorbed is known as imbibate and the solid adsorbent which cause imbibition or adsorption is called imbibant.
- The classical examples of imbibition are adsorption of water by seeds and dry wood.
- Affinity is must between imbibant and liquid material and movement of water occurs according to water potential gradient. (These are two pre-requisite for imbibition)
- Agar - agar, starch etc, these all are imbibant materials.
  Imbibition power = Agar – Agar > Pectin > Protein > Starch > Cellulose
- A pressure is developed in material due to imbibition. This pressure is called Imbibition pressure (IP).
- Dry wood is filled in the natural grooves of rocks and then watered. The rocks get broken due to the swelling of wood. (Method used by prehistoric men)

➢ **Significance of Imbibition:**

(1) Absorption of water during the seed germination is initiated by the imbibition. Breaking of seed coat during the seed germination is due to imbibition pressure.

(2) Seedlings emerge out of the soil into the open due to imbibition pressure.

★ Golden Key Points ★

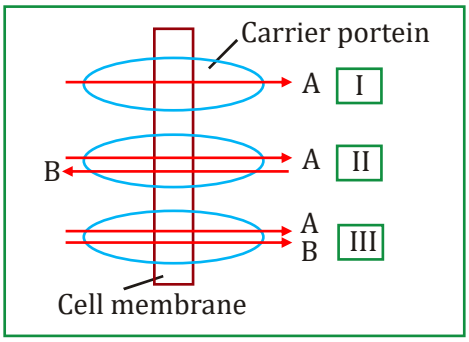
- **In rooted plants transport in xylem (of water and minerals) is unidirectional, from roots to stem.**
- Organic compounds synthesised in the photosynthetic leaves are exported to all other parts of the plant including storage organs. From the storage organs they are later re-exported.
- In facilitated diffusion, specific proteins help in transfer of substances across the membrane and no ATP is consumed.
- The net direction and rate of osmosis depends on both the pressure gradient and concentration gradient.
- **If a plant cell is placed in a hypertonic solution, water diffuses out of the cell. Water first lost from cytoplasm then from vacuole.**
- **Water always flows from higher water potential to lower water potential.**
- **Adsorption of liquid by any solid material is called imbibition. It is also a type of diffusion.**

BEGINNER'S BOX-1

INTRODUCTION, TYPES OF TRANSPORT, PERMEABILITY, TYPES OF SOLUTIONS, PLANT WATER RELATIONS

1. Select the incorrect statement regarding facilitated diffusion.
(1) It is a very specific process.
(2) It is a passive process.
(3) It helps the hydrophilic substances to be transported across the membrane.
(4) It is not under any hormonal regulation.

2. The given figure shows transport of two molecules A and B through three different modes of facilitated diffusion.



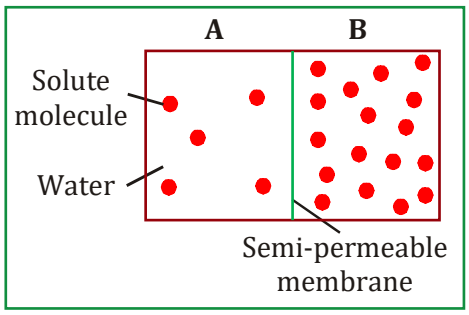
Select the correct option regarding it.

	I	II	III
(1)	Uniport	Symport	Antiport
(2)	Uniport	Antiport	Symport
(3)	Antiport	Uniport	Symport
(4)	Antiport	Symport	Uniport

3. If ψ_w = water potential; ψ_s = solute potential; ψ_p = pressure potential, then select the correct equation showing their inter-relation :-
(1) $\psi_w = \psi_s - \psi_p$ (2) $\psi_w = \psi_s + \psi_p$ (3) $\psi_s = \psi_w + \psi_p$ (4) $\psi_w = \psi_s = \psi_p$

4. If a cell A with DPD = 5 bars is connected to cells B, C and D, whose OP and TP are respectively 5 and 5, 10 and 4, and 8 and 3, the flow of water will be :-
(1) C to A, B to D (2) A and D to B and C
(3) A to B, C and D (4) B to A, C and D

5. Based on the given figure which of the following statements is not correct?



(1) Movement of solvent molecules will take place from chamber A to B.
(2) Movement of solute molecules will take place from A to B.
(3) Presence of a semipermeable membrane is a pre-requisite for this process to occur.
(4) The direction and rate of the process depends on both the pressure gradient and concentration gradient.

6. Diffusion is a :-
(1) Passive process (2) Random process
(3) Slow process (4) All of these

7. Diffusion can occur between :-
(1) One part of cell to other part (2) Cell to cell
(3) Intercellular space to outside of leaf (4) All of these

8. Diffusion rate is affected by :-
(1) Concentration gradient (2) Membrane permeability
(3) Pressure and temperature (4) All of these

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9. Long distance transport is takes place through :-
(1) Xylem (2) Phloem (3) Cells (4) Both (1) and (2)

10. Exchange of gases between plant and atmosphere is governed by :-
(1) Osmosis (2) Diffusion
(3) Permeability of cell wall (4) Active transport

11. The potential energy of water is referred to as :-
(1) Water potential (2) Osmotic potential
(3) Gravity potential (4) Pressure potential

12. Porins are the proteins that form huge pores in the :-
(1) Outer membrane plastids (2) Outer membrane of mitochondria
(3) Plasma membrane of some bacteria (4) All of these

13. When a molecule moves across a membrane independent of other molecules, the process is known as :-
(1) Uniport (2) Antiport (3) Symport (4) All of these

14. Water channels are made up of ..... different types of aquaporins:-
(1) Four (2) Six (3) Eight (4) Ten

15. When molecules moves in opposite directions the process is known as:-
(1) Uniport (2) Antiport (3) Symport (4) All of these

6. Transpiration :

- **Loss of water in form of vapour from the aerial parts (flower, fruit, leaves, stem) of living plants is known as Transpiration.**
- **"Transpiration is an essential evil"- by Curtis.**
- **"Transpiration is an unavoidable evil"-by Steward.**
- The minimum transpiration is found in succulent xerophytes. Maximum transpiration is found in mesophytes.
- Transpiration is absent in algae, fungi and submerged aquatic plants.

(A) Types of Transpiration :

Transpiration is of following three types :-

(i) Stomatal Transpiration :-

- Transpiration takes place through the stomata which are present on the leaves of the plants and delicate organs, it is called stomatal transpiration. The maximum amount of water is lost by stomatal transpiration **(50-90% of total transpiration).**

(ii) Cuticular Transpiration :-

- Loss of water through the cuticle which is present on the herbaceous stem and leaves is cuticular transpiration. Cuticle is a wax like thin layer present on epidermis. About **9% to 9.9%** transpiration is cuticular.

(iii) Lenticular Transpiration :-

- Minute pore like structures found on the stem of some woody plants and epidermis of some fruits are called lenticels. Some amount of water is lost by lenticels, known as lenticular transpiration. However it contributes approximately **0.1% to 1%** of the total water lost.
- **Foliar transpiration :** Total transpiration occurring through the leaves is called as foliar transpiration.
- Foliar transpiration = Stomatal + Cuticular (from the leaves.)

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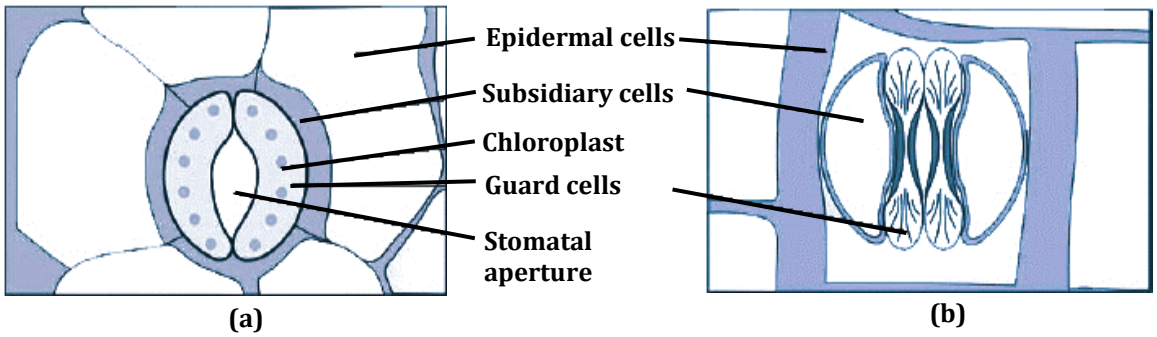
(B) Structure of Stoma :



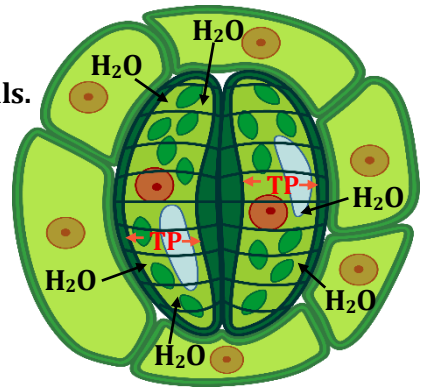
Diagrammatic representation: (a) stomata with bean-shaped guard cells (b) stomata with dumb-bell shaped guard cell

- Stomata are found on the aerial delicate organs and on surface of the leaves in the form of minute pores. Stomatal pore is surrounded by two specialised epidermal cells called as guard cells. They are **kidney shaped (Reniform) or bean shaped or Crescent shape. Guard cells have chloroplasts. (Differ from other leaf epidermal cells in this character).**
- The shape of guard cells in monocots (Graminae or Poaceae or grass family) is dumb-bell shaped.
- **The outer wall of the guard cells is thin and elastic while inner wall is thick and elastic. In the walls of guard cells there are radially arranged cellulose microfibrils.**
- Guard cells are surrounded by some specialized epidermal cells called subsidiary cells or accessory cells.
- Air chamber below the stomata is called sub-stomatal cavity.

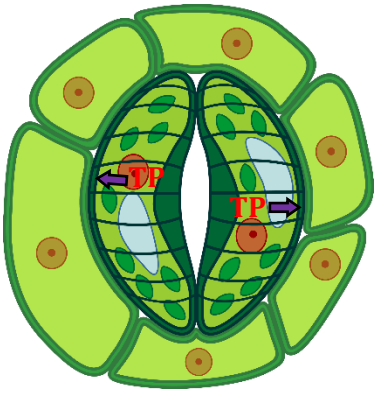
(C) Mechanism of Opening And Closing of Stomata :

- The cause of the opening or closing of the stomata is a change in the turgidity of the guard cell. When guard cells become turgid, stomata opens and when guard cells become flaccid, stomata closes.
- When osmotic concentration (OP) of guard cells is high, then guard cells become turgid by absorption of water through endosmosis from near by cells (Subsidiary cells).
- When osmotic concentration (OP) of guard cells decreases then guard cells become flaccid. Due to flaccidity of guard cells, inner thick walls of both guard cells become fused and stomata closes.
- **The opening of the stoma is also aided due to the orientation of the microfibrils in the cell walls of the guard cells. Cellulose microfibrils are oriented radially rather than longitudinally making it easier for the stoma to open.**

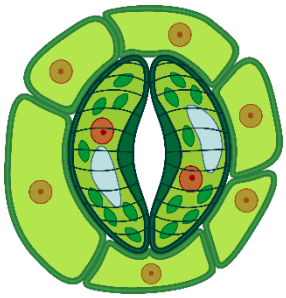
- **Due to endosmosis TP develop in Guard cells.**
- **It exerts pressure over the cell wall.**



- Radially oriented cellulosic
- Micro fibrils stretches cell wall.



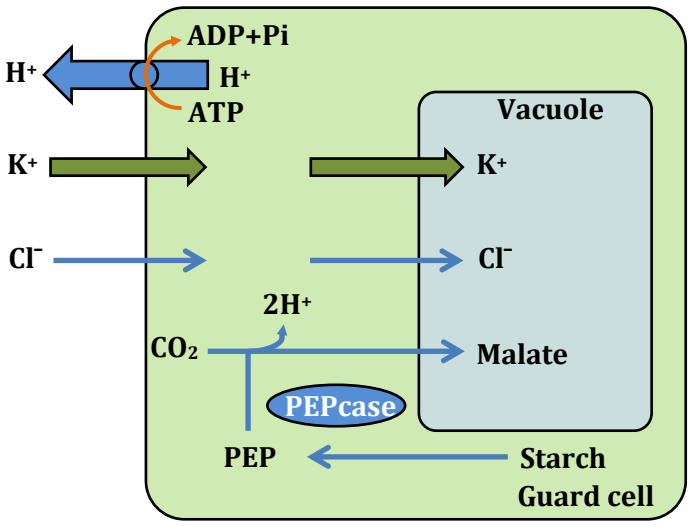
- Stoma Open



ACTIVE $K^+ \rightleftharpoons H^+$ EXCHANGE THEORY OR ACTIVE POTASSIUM TRANSPORT

Mechanism :

- This is modern & most accepted theory for stomatal opening.
- First of all **Fujino** observed influx of K^+ ions in guard cells during stomatal opening. Detail study of this phenomenon was done by **Levitt**. According to him stomata open by following mechanism–



- When Plant hormone ABA is formed in guard cells, it interferes with the exchange of $K^+ \rightleftharpoons H^+$ in guard cells, resulting in reverse reaction of opening of stomata, hence stomata get closed.
- High concentration of K^+ ions in guard cells is electrically balanced by uptake of Cl^- and malate ions which are present in guard cells.

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(D) Factors Affecting The Rate of Transiration :

➢ **Factors affecting the rate of transpiration are divided into two types :-**

[A] External factors (Environmental factors)

[B] Plant Factors

[I] External factors :

(a) Atmospheric Humidity :- $T_r \propto \frac{1}{\text{Atmospheric humidity}}$

- This is the most important factor.
- At higher atmospheric humidity transpiration may stop but stomata remain completely open.

(b) Temperature : $T_r \propto \text{Temperature}$

- The value of Q_{10} for transpiration is 2. It means by increasing 10^0C temperature, the rate of transpiration becomes approximately double.
- Water vapour holding capacity of air is increased at high temperature, so the rate of transpiration is increased. On contrary vapour holding capacity of air is decreased at low temperature so the rate of transpiration is decreased.

(c) Light :-

- Light increases, transpiration by heating effect on leaf.
- **Action Spectrum of transpiration is blue and red.**

(d) Wind Velocity : $T_r \propto \text{Wind Velocity}$

- Transpiration increases with the increase in wind velocity and vice versa, because wind removes humid air (saturated air) around the stomata.

(e) Atmospheric Pressure :- $T_r \propto \frac{1}{\text{Atmospheric pressure}}$

[II] Plant (or internal) factors :

(a) Stomata :

(i) Number of stomata : Rate of transpiration is directly proportional to number of stomata.

(ii) Distribution of stomata : Distribution of stomata is variable usually the lower surface of a dorsiventral (often dicotyledonous) leaf has a greater number of stomata while in an isobilateral (Often monocotyledonous) leaf, they are about equal on both surfaces.

Therefore, monocots transpire more than dicots.

(iii) Percentage of open stomata : Rate of transpiration is directly proportional to percentage of open stomata.

(b) Anatomy of leaf :

(i) Mesophyll : Occurrence of pallisade tissue in cortex of leaf (mesophyll) helps to reduce transpiration, while spongy mesophyll favour high rate of transpiration.

(ii) Cuticle : Rate of transpiration is inversely proportional to thickness of cuticle. In xerophytes thick cuticle is an adaptation to minimise the loss of water.

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(c) Water status of the plant :
Less than one percent of the water reaching the leaves is used in photosynthesis and plant growth. Most of absorbed water lost through transpiration, thus a good status of water favours high rate of transpiration. Due to water stress ABA forms in gaurd cells and stimulates closing of stomata (hence, decrease in transpiration).

(d) Canopy structure : Dense canopy causes decrease in transpiration because such canopy obstruct air flow.

(e) Root shoot ratio : Transpiration per unit area is directly proportional to root shoot ratio.

Some facts about transpiration :

Antitranspirants : Substances which reduce the rate of transpiration are known as antitranspirants. They are very useful in dry farming. **Examples :** Phenyl Mercuric Acetate [PMA], aspirin (salicylic acid), ABA, oxy-ethylene, silicon oil, CO_2 and low viscosity wax.

Transpiration ratio : Rate of the loss of water to the photosynthetic CO_2 fixed is called transpiration ratio.

$$\text{Transpiration ratio} = \frac{\text{Moles of } H_2O \text{ transpired}}{\text{Moles of } CO_2 \text{ assimilated}}$$

This ratio is low for C_4 plants (200-350) while high for C_3 plants (500-1000) which indicates C_4 plants conserve water with efficient photosynthesis. Transpiration ratio of CAM plants is minimum (50-100).

- **In xerophytes stomata are sunken to minimise the loss of water.**

Transpiration and Photosynthesis: A Comparision :

Transpiration has more than one purpose; it

- **creates transpiration pull for absorption and transport of plants**
- supplies water for photosynthesis
- transports minerals from the soil to all parts of the plant
- **cools leaf surfaces, sometimes 10 to 15 degrees, by evaporative cooling**
- maintains the shape and structure of the plants by keeping cells turgid

An actively photosynthesising plant has an insatiable need for water. Photosynthesis is limited by available water which can be swiftly depleted by transpiration. The humidity of rainforests is largely due to this vast cycling of water from root to leaf to atmosphere and back to the soil.

7. Long Distance Transport (Translocation) :

- In large and complex organisms, often substances have to be moved across very large distances. Sometimes the sites of production or absorption and sites of storage are too far from each other; diffusion or active transport would not suffice.
- Long distance transport of water, minerals and food occurs generally by mass or bulk flow system.
- Mass flow is the movement of substances in bulk or en masse from one point to another as a result of pressure difference between the two points.
- It is a characteristic of mass flow that substances, whether in solution or in suspension, are swept along at the same pace, as in a flowing river. This is unlike diffusion where different substances move independently depending on their concentration gradients.

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- Bulk flow can be achieved either through a positive hydrostatic pressure gradient/pushing pressure (e.g. a garden hose) or a negative hydrostatic pressure gradient/pulling pressure (e.g. suction through a straw).

(A) How Do Plants Absorb Water?

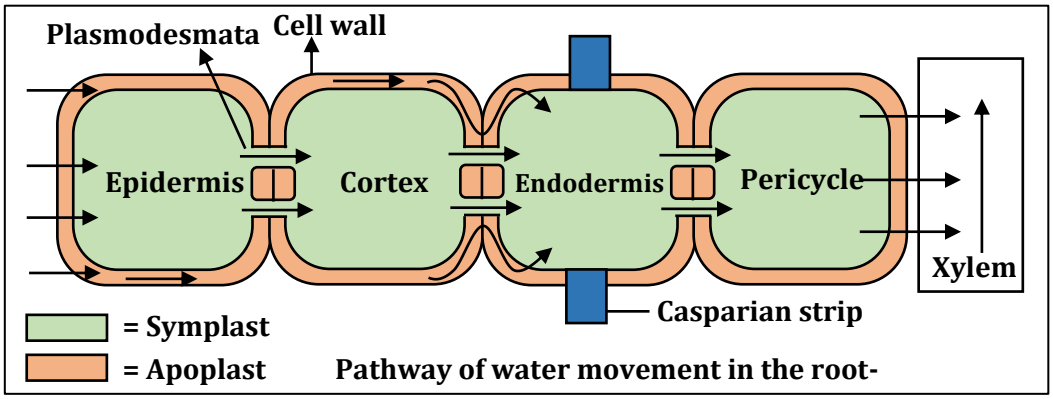
- We know that the roots absorb most of the water that goes into plants; obviously that is why we apply water to the soil and not on the leaves.
- The responsibility of absorption of water and minerals is more specifically the function of the root hairs that are present in millions at the tips of the roots.
- Root hairs are thin-walled slender extensions of root epidermal cells that greatly increase the surface area for absorption. Water is absorbed along with mineral solutes, by the root hairs, purely by diffusion.
- Once water is absorbed by the root hairs, it can move deeper into root layers by two distinct pathways:
  - **Apoplast pathway**
  - **Symplast pathway**

Apoplast Pathway :

- **The apoplast is the system of adjacent cell walls that is continuous throughout the plant, except at the casparian strips of the endodermis in the roots.** The apoplastic movement of water occurs exclusively through the intercellular spaces and the walls of the cells. Movement through the apoplast does not involve crossing the cell membrane. This movement is dependent on the gradient. The apoplast does not provide any barrier to water movement and water movement is through mass flow. As water evaporates into the intercellular spaces or the atmosphere, tension develop in the continuous stream of water in the apoplast, hence mass flow of water occurs due to the adhesive and cohesive properties of water.

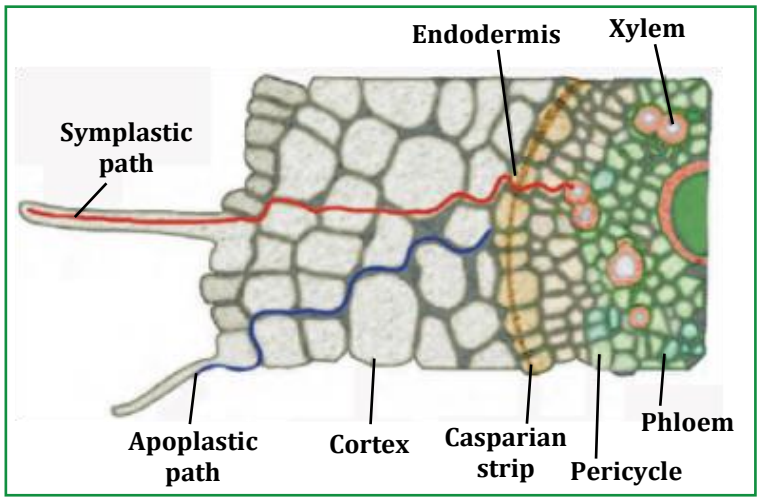
Symplast Pathway :

- **The symplastic system is the system of interconnected protoplasts. Neighbouring cells are connected through cytoplasmic strands that extend through plasmodesmata.** During symplastic movement, the water travels through the cells – their cytoplasm; intercellular movement is through the plasmodesmata. Water has to enter the cells through the cell membrane, hence the movement is relatively slower. Movement is again down a potential gradient. **Symplastic movement may be aided by cytoplasmic streaming.**



Pathway of water movement in the root-

- **Most of the water flow in the roots occurs via the apoplast since the cortical cells are loosely packed, and hence offer no resistance to water movement.**
- However, the inner boundary of the cortex, the endodermis, is impervious to water because of a band of suberised matrix called the casparian strip. Water molecules are unable to penetrate the layer, so they are directed to wall regions that are not suberised, into the cells proper through the membranes. The water then moves through the symplast and again crosses a membrane to reach the cells of the xylem. The movement of water through the root layers is ultimately symplastic in the endodermis. This is the only way water and other solutes can enter the vascular cylinder.



- Once inside the xylem, water is again free to move between cells as well as through them. In young roots, water enters directly into the xylem vessels and/or tracheids. These (xylem vessels and tracheids) are non-living conduits and so are parts of the apoplast.

➢ **Mycorrhiza :-**

A mycorrhiza is a symbiotic association of a fungus with a root system. The fungal hyphae present on/in the root have a very large surface area that absorb mineral ions and water from the soil from a much larger volume of the soil that perhaps a root can not do. The fungus provides minerals and water to the roots. In turns the roots provide sugar and N-compounds to the fungi.

e.g. Pinus seeds cannot germinate and establish without the mycorrhiza. (Obligate association)

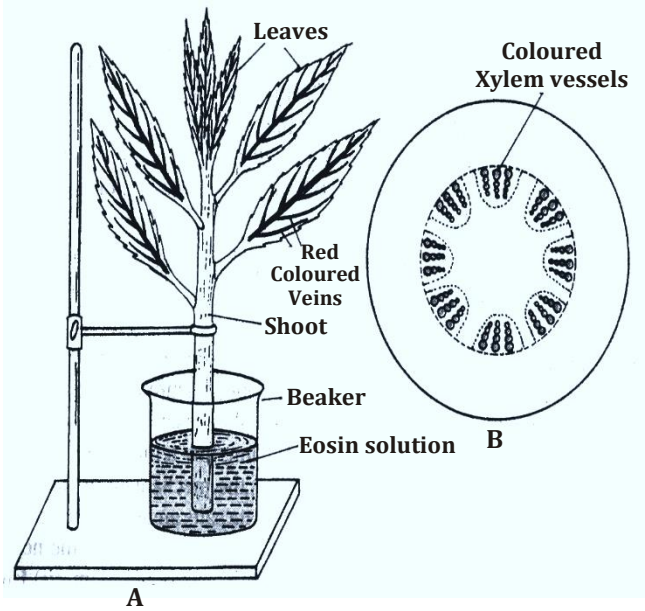
(B) Water Movement up A Plant (Ascent of Sap) :

Upward movement of absorbed water against the gravitational force upto top parts of plants is called as ascent of sap. [Translocation of sap (water + minerals) takes place by xylem]

Experiment :

- Place a twig bearing white flowers (Balsam plant) in coloured water (eosin solution). On examining the cut end of the twig after a few hours we will notice the region through which the coloured water moved. This experiment very easily demonstrates that the path of the water movement is through the xylem.

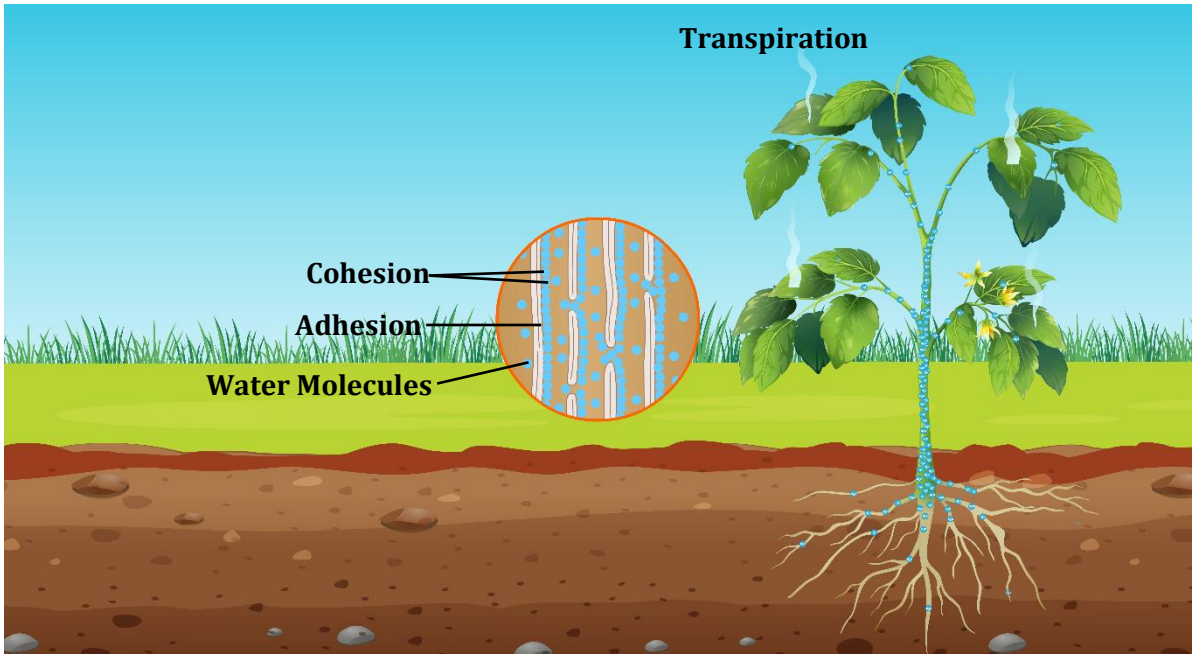
- As water evaporates through the stomata, since the thin film of water over the cells is continuous, it results in pulling of water, molecule by molecule, into the leaf from the xylem. Also, because of lower concentration of water vapour in the atmosphere as compared to the substomatal cavity and intercellular spaces, water diffuses into the surrounding air. This creates a 'pull'.



➢ **Mechanism of ascent of sap :-**

➢ **Cohesion - tension - transpiration pull model :- By Dixon & Jolly.**

- Most accepted or universally accepted theory for explaining mechanism of ascent of sap.
- According to it following components are involved in ascent of sap :-



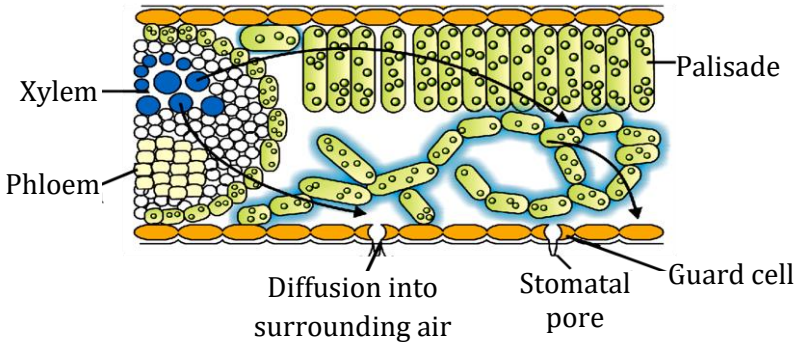
(a) **Transpiration Pull : A negative pressure (pulling pressure) develops in xylem due to rapid transpiration in leaves, this is called transpiration pull which is responsible for the pulling of water column in xylem.** Measurements reveal that the force generated by transpiration can create pressures sufficient to lift a xylem sized column of water over 130 metres high. (with the rate of about 15 metres per hour).

(b) **Cohesion :** Mutual attraction between the water molecules is known as cohesion, which helps to forms a continuous water column in xylem elements.

(c) **Adhesion :** Attraction between xylem walls & water molecules is called adhesion force.

(d) **Surface tension :** Water molecule are attracted to each other in the liquid phase more than the water molecules in gas phase.

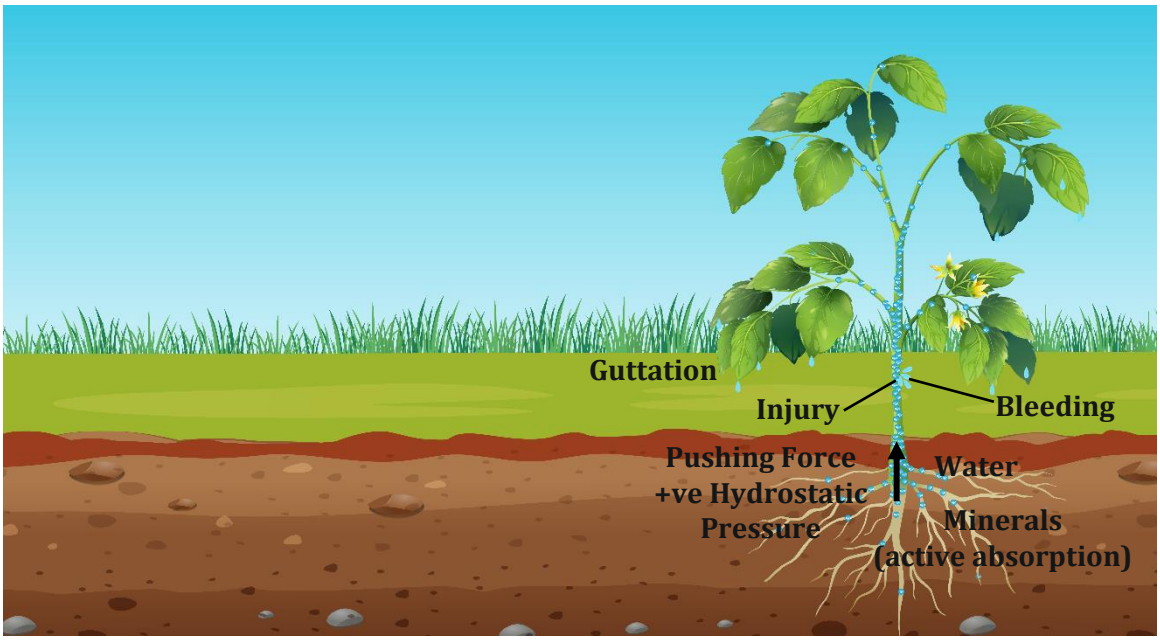
- **Cohesion, Adhesion and surface tension properties give water high tensile strength means ability to resist pulling force and also give water high capillarity means ability to rise in thin tubes. In plants capillarity is aided by the small diameter of the tracheids and vessels.**



Water movement in the leaf. Evaporation from the leaf sets up a pressure gradient between the outside air and the air spaces of the leaf. The gradient is transmitted into the photosynthetic cells and on the water-filled xylem in the leaf vein.

(C) Root Pressure :

- **As various ions from the soil are actively transported into the vascular tissues of the roots, water follows (due to its water potential gradient) and increases the pressure inside the xylem. This positive pressure is called root pressure,** and can be responsible for pushing up water to small heights in the stem.



Experiment for demonstration of root pressure :

- Choose a small soft-stemmed plant on a day, when there is plenty of atmospheric moisture and cut the stem horizontally near the base with a sharp blade, early in the morning, soon we will see drops of solution ooze out from the cut stem; this comes out due to the positive root pressure.
- By fixing a rubber tube to the cut stem as a sleeve we can actually collect and measure the rate of exudation, and also determine the composition of the exudates.
- **The greatest contribution of root pressure may be to re-establish the continuous chains of water molecules in the xylem which often break under the enormous tensions created by transpiration.**
- Root pressure only provides a modest push in the overall process of water transport.
- Root pressure does not account for the majority of water transport; most plants meet their need by transpiratory pull.

(D) Guttation :

- **Loss of water from the margins of leaves in the form of water droplets (liquid phase) is called guttation.**
- Process of guttation occurs in herbaceous plants. When water absorption is high and transpiration is low.
- The exiting water due to guttation has some organic and inorganic compounds (mainly) also. **It means it is not pure water.**
- Normally, guttation process is found in some plants like Grasses, Tomata, Balsum and in plants of Cucurbitaceae family.
- Guttation occurs from the margins of the leaves through the special pore (always open) like structures, called as Hydathodes or Water stomata.
- Generally guttation occurs during night or early morning.
- **Parenchymatous and loose tissue lies beneath the hydathode which is known as epithem tissue.**
- **The process of guttation occurs due to the root pressure.**

(E) Bleeding/Exudation :

- **Oozing of liquid from the freshly injured or cut parts of the plants is called bleeding or exudation.**
- This process takes place due to high root pressure.
- Sugar is obtained from the sugar maple by this process. **Opium and rubber** is obtained by this process.
- The maximum bleeding is found in caryota urens (Toddy palm) (about 50 litres per day).]

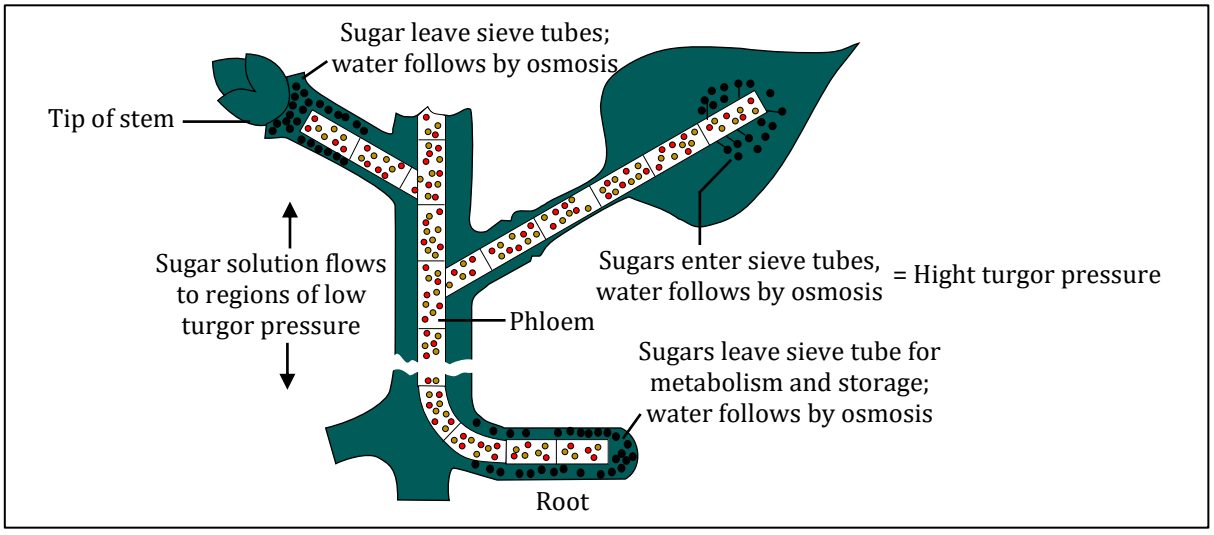
8. Phloem Transport (Food Translocation In Plants) :

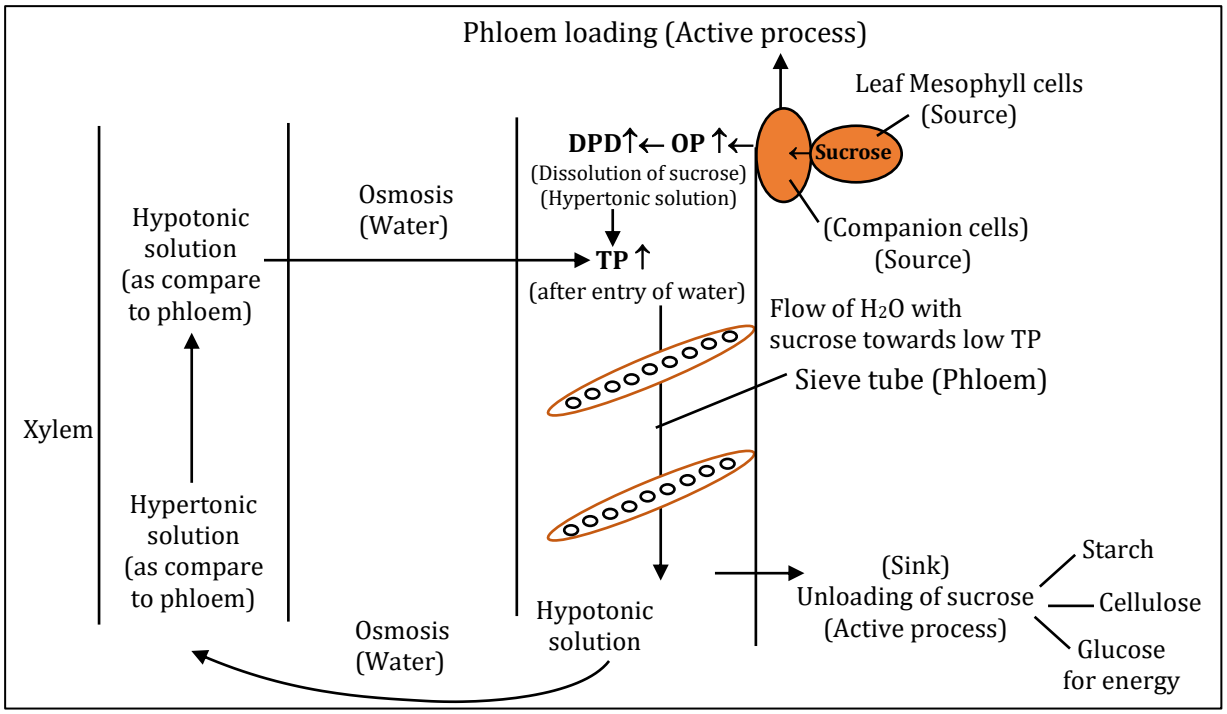
- **Food/organic material conduction in plants occurs by phloem.**
- Generally green photosynthetic plant parts act as **source like leaves** while non-photosynthetic parts like **root, shoot, fruits act as sink.** Food conduction occurs from source to sink.
- **Food transfer depends on requirement of plant and seasonal activities**. For example, in germinating potato tuber, tuber acts as source and developing buds acts as sink, similarly in early spring roots act as source and developing buds as sink.

- Food conduction may occur in any required direction (Bidirectional) unlike the water conduction which is a unidirectional process.
- **Translocation of food occurs in the form of sucrose because it is osmotically active and a non-reducing sugar so remain chemically inert in it's pathway of conduction.**
- **Phloem sap is mainly water and sucrose. But other sugars, hormones, amino acids and inorganic solutes are also transported or translocated through phloem.**

The Pressure Flow or Mass Flow Hypothesis :

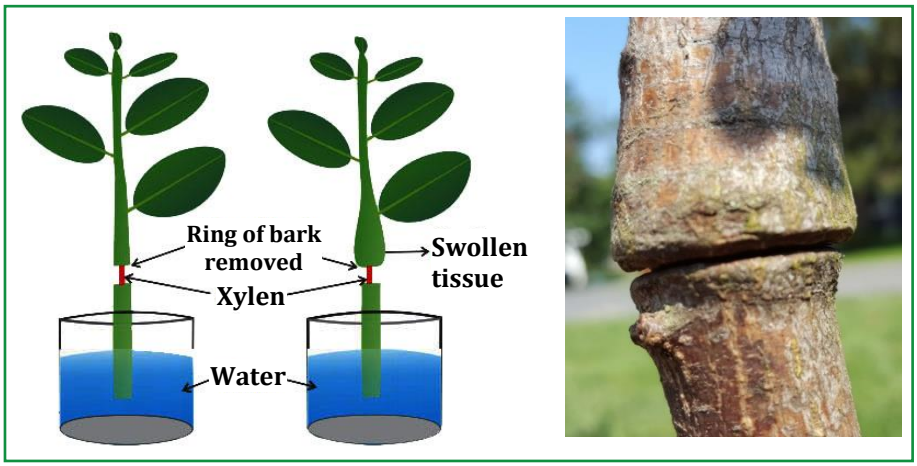
- **The accepted mechanism used for the translocation of sugars from source to sink is called the pressure flow hypothesis. (proposed by E. Munch).**
- As glucose is prepared at the source (by photosynthesis) it is converted to sucrose (a dissacharide). The sugar is then moved in the form of sucrose into the companion cells and then into the living phloem sieve tube cells by active transport. This process of loading at the source produces a hypertonic condition in the phloem. Water in the adjacent xylem moves into the phloem by osmosis. **As turgor pressure builds up the phloem sap will move to areas of lower pressure. Again active transport is necessary to move the sucrose out of the phloem sap and into the cells which will use the sugar – converting it into energy, starch, or cellulose. As sugars are removed, the osmotic pressure decreases and water moves out of the phloem.**
- To summarise, the movement of sugars in the phloem begins at the source, where sugars are loaded (actively transported) into a sieve tube. Loading of the phloem sets up a water potential gradient that facilitates the mass movement in the phloem.
- Phloem tissue is composed of sieve tube cells, which form long columns with holes in their end walls called sieve plates. Cytoplasmic strands pass through the holes in the sieve plates, so forming continuous filaments. As hydrostatic pressure (Turgor pressure) in the phloem sieve tube increases, pressure flow begins, and the sap moves through the phloem. Meanwhile, at the sink, incoming sugars are actively transported out of the phloem and removed as complex carbohydrates. **The loss of solute produces a high water potential in the phloem, and water passes out, returning eventually to xylem.**





Girdling :

- A simple experiment, called **girdling,** was used to identify the tissues through which food is transported. On the trunk of a tree a ring of bark up to a depth of the phloem layer, can be carefully removed. In the absence of downward movement of food the portion of the bark above the ring on the stem becomes swollen after a few weeks. This simple experiment shows that phloem is the tissue responsible for translocation of food; and that transport takes place in one direction, i.e., towards the roots.



- **Cobalt chloride test :** This experiment is used for the comparison of rate of transpiration from both surfaces of the leaves.
- **Porometer** is used to find out the diameter of the stomatal pores present on the leaf.
- Transpiration measuring instrument is **potometer**. The rate of absorption of water is measured by this instrument, which is directly proportional to the rate of transpiration.
- **Manometer** is used to measure root pressure.

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Golden Key Points

- The cause of the opening or closing of the stomata is a change in the turgidity of the guard cell.
- Transpiration **cools leaf surfaces, sometimes 10 to 15 degrees, by evaporative cooling.**
- It is a characteristic of mass flow that substances, whether in solution or in suspension, are swept along at the same pace, as in a flowing river.
- **The apoplast is the system of adjacent cell walls that is continuous throughout the plant, except at the casparian strips of the endodermis in the roots.**
- **The symplastic system is the system of interconnected protoplasts.**
- **Cohesion, Adhesion and surface tension properties give water high tensile strength means ability to resist pulling force and also give water high capillarity means ability to rise in thin tubes.**
- **The greatest contribution of root pressure may be to re-establish the continuous chains of water molecules in the xylem which often break under the enormous tensions created by transpiration.**
- **Loss of water from the margins of leaves in the form of water droplets (liquid phase) is called guttation.**
- A simple experiment, called **girdling**, was used to identify the tissues through which food is transported.

BEGINNER'S BOX-2

TRANSPIRATION, LONG DISTANCE TRANSPORT, PHLOEM TRANSPORT

1. Stomata : Transpiration : : Hydathode : _____.
(1) Guttation (2) Root pressure (3) Bleeding (4) Oozing

2. Which one of the following will not directly affects transpiration?
(1) Temperature (2) Light
(3) Wind speed (4) Chlorophyll content of leaves

3. Ascent of sap is best explained by
(1) facilitated diffusion (2) simple diffusion
(3) root pressure (4) cohesion-tension transpiration pull.

4. Match Column-I with Column-II and select the correct option from the codes given below.

Column-I		**Column-II**
A. Leaves	(i)	Anti-transpirant
B. Seeds	(ii)	Transpiration
C. Roots	(iii)	Negative pressure potential
D. Aspirin	(iv)	Imbibition
E. Plasmolysed cell	(v)	Absorption

(1) A-(iii), B-(iv), C-(i), D-(ii), E-(v) (2) A-(i), B-(ii), C-(iii), D-(iv), E-(v)
(3) A-(ii), b-(iv), C-(v), D-(iii), E-(i) (4) A-(ii), B-(iv), C-(v), D-(i), E-(iii)

5. In plants food transports as sucrose which is an –
(1) Osmotically inactive and chemically inert sugar
(2) Osmotically active and chemically inert sugar
(3) Osmotically inactive and chemically reactive sugar
(4) Osmotically active and chemically reactive sugar

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6. Transpiration is absent in which of the following plants ?
(1) Algae (2) Fungi
(3) Submerged aquatic plants (4) All of these

7. Which among the following contributes the maximum in transpiration?
(1) Cuticular transpiration (2) lenticular transpiration
(3) Stomatal transpiration (4) None of the above

8. When the guard cells become turgid, stomata will-
(1) Open (2) closed
(3) Remains in same condition (4) None of the above

9. Maximum transpiration is found in-
(1) Succulent xerophytes (2) Mesophytes
(3) Hydrophytes (4) Halophytes

10. Active K^+-H^+ exchange theory is proposed by-
(1) Curtis (2) Steward (3) Levitt (4) Munch

11. Which among the following is most important factor affecting the rate of transpiration ?
(1) Atmospheric Humidity (2) Temperature
(3) Light (4) wind velocity

12. The value of Q_{10} for transpiration is -
(1) One (2) two (3) three (4) four

13. Transpiration is inversely proportional to -
(1) Atmospheric pressure (2) wind velocity
(3) Atmospheric humidity (4) Temperature

14. Which among the following is not a plant factor ?
(1) Number of opened stomata (2) Canopy structure
(3) Number and distribution of stomata (4) Temperature

15. Process responsible for evaporative cooling is -
(1) Photorespiration (2) photosynthesis
(3) Transpiration (4) Root pressure

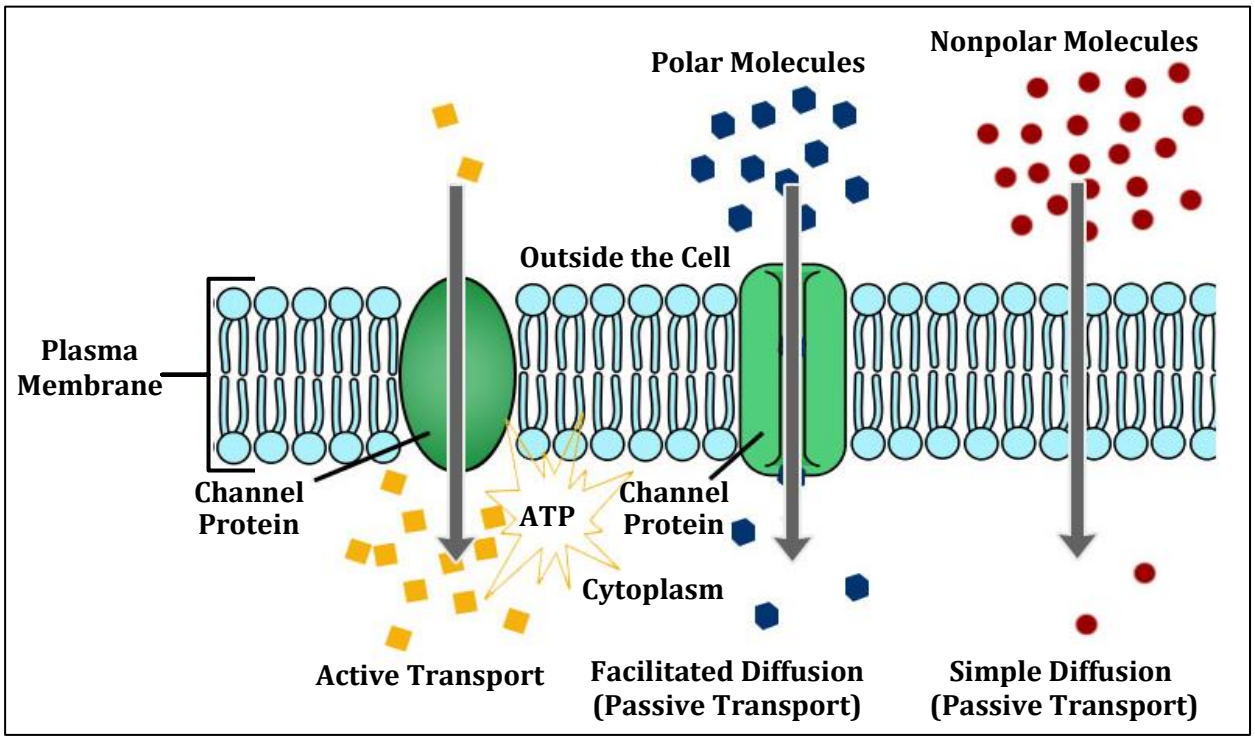
BEGINNER'S BOX — ANSWERS KEY

BEGINNER'S BOX-1	**Que.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Ans.	**4**	**2**	**2**	**4**	**2**	**4**	**4**	**4**	**4**	**2**
	Que.	**11**	**12**	**13**	**14**	**15**					
	Ans.	**1**	**4**	**1**	**3**	**2**					

BEGINNER'S BOX-2	**Que.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Ans.	**1**	**4**	**4**	**4**	**2**	**4**	**3**	**1**	**2**	**3**
	Que.	**11**	**12**	**13**	**14**	**15**					
	Ans.	**1**	**2**	**1**	**4**	**3**					

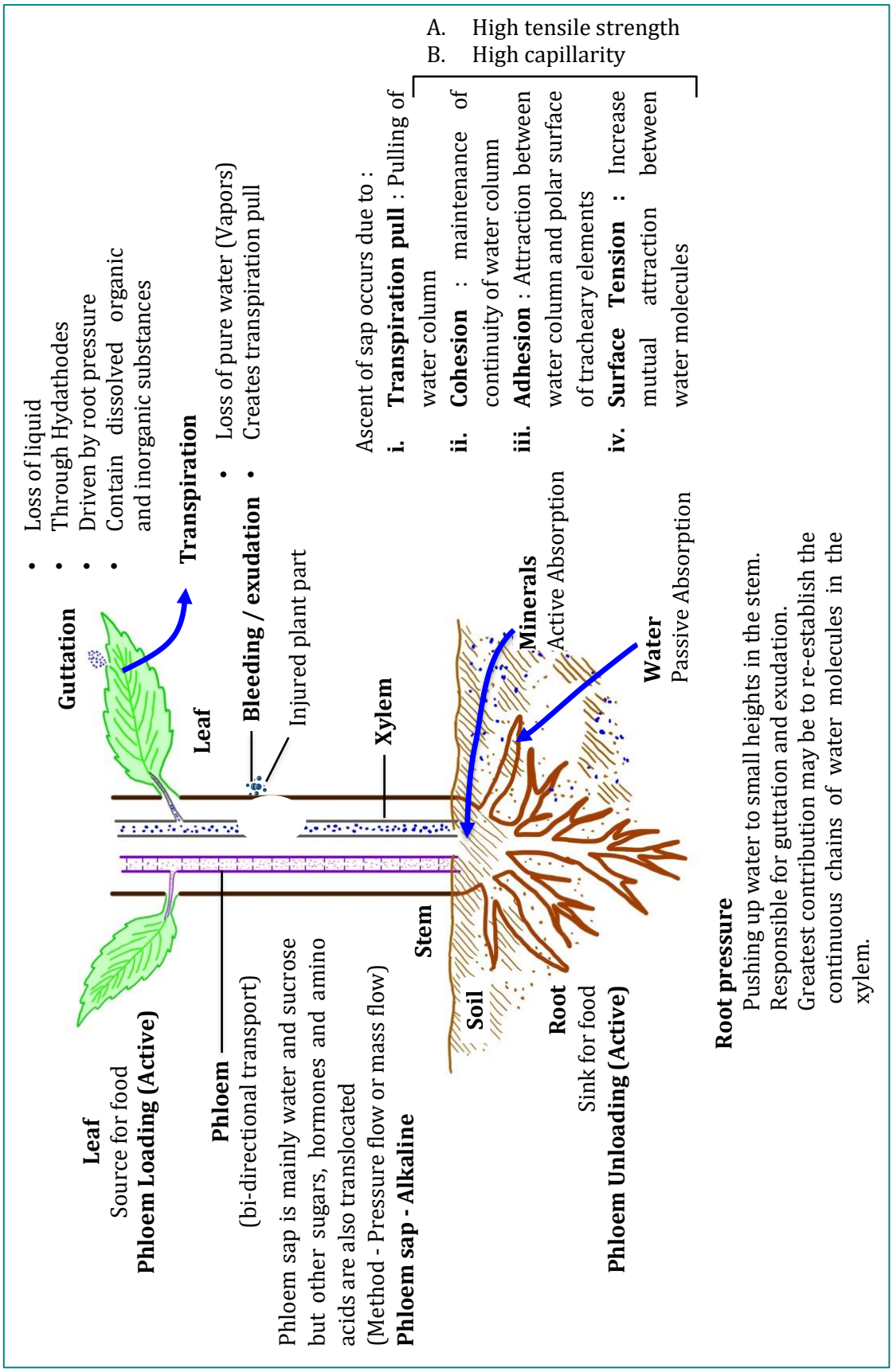
Transmembrane Proteins :

- **Channel or Tunnel proteins**
- **Pump Proteins**
- **Porins :** large pores in the outer membranes of the plastids, mitochondria and some bacteria



Osmosis is the term used to refer specifically to the diffusion of water across a differentially or selectively permeable membrane.

- In thermodynamics free energy of water is called water potential (Ψw). Two main components that determine water potential are :
  (a) Solute potential or osmotic potential (Ψs), **(b)** Pressure potential (Ψp)
- If some solute is dissolved in pure water, reducing its water potential. The magnitude of this lowering due to dissolution of a solute is called **solute potential or osmotic potential (Ψs)**
- If a pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. This increase is called **pressure potential** (Ψp)
- Water potential of a cell is affected by both solute potential and pressure potential. **[Ψw = Ψs + Ψp]**


A. High tensile strength
B. High capillarity
Ascent of sap occurs due to :
i. Transpiration pull : Pulling of water column
ii. Cohesion : maintenance of continuity of water column
iii. Adhesion : Attraction between water column and polar surface of tracheary elements
iv. Surface Tension : Increase mutual attraction between water molecules
Transpiration
• Loss of liquid
• Through Hydathodes
• Driven by root pressure
• Contain dissolved organic and inorganic substances
• Loss of pure water (Vapors)
• Creates transpiration pull
Guttation
Leaf
Bleeding / exudation
Injured plant part
Xylem
Minerals
Active Absorption
Water
Passive Absorption
Leaf
Source for food
Phloem Loading (Active)
Phloem
(bi-directional transport)
Phloem sap is mainly water and sucrose but other sugars, hormones and amino acids are also translocated
(Method - Pressure flow or mass flow)
Phloem sap - Alkaline
Stem
Soil
Root
Sink for food
Phloem Unloading (Active)
Root pressure
Pushing up water to small heights in the stem.
Responsible for guttation and exudation.
Greatest contribution may be to re-establish the continuous chains of water molecules in the xylem.